APPLICATIONS OF A SMALL ELECTRONIC DIGITAL COMPUTER TO PYROMETALLURGICAL RESEARCH

By R. J. Leary, R. W. Smith, Jr., and B. J. Mitchel

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APPLICATIONS OF A SMALL ELECTRONIC DIGITAL COMPUTER TO PYROMETALLURGICAL RESEARCH[1]

by

R. J. Leary[2], R. W. Smith, Jr.[3], and B. J. Mitchel[4]

SUMMARY

A small electronic digital computer employing punched cards has been used to facilitate the solution of a variety of problems in Bureau of Mines pyrometallurgical research. In this work the computer has been found to be economical for solving both simple problems that occur repeatedly and those involving complex or iterative calculations. Each of these classes of problems and their respective solutions are described.

These small computers can be used effectively by researchers when they work in consultation with a computer specialist. Close team work produces the required solutions in less time, and, oftentimes, in a more useful form. Participation in programming by researchers develops in them a skill for evaluating the suitability of problems for electronic computing.

Small computers are useful and economical for solving a much broader range of problems in scientific calculations than is generally appreciated by scientists who are unfamiliar with the versatility, speed, and low cost of electronic computing. On the other hand, computer technologists perceive the limitations of a small computer by comparing it to larger ones, and may overlook two advantages of small computers over desk calculators: (1) They relieve the tedium and operational errors that inhere to hand calculation, and (2) they extend the scope and magnitude of problems that can be handled by laboratories whose computer traffic would not justify a large computer.

INTRODUCTION

All digital computers work with numbers in their numerical form; in this respect, a desk calculator is a digital computer. The other common class of computers, the analogue type, works with numbers expressed as a physical quantity; the simplest and best known of these is the slide rule, which uses lengths as proportional to the logarithms of numbers. For arithmetic operations digital computers are inherently capable of greater precision in representing numbers. The practical advantage of this type, however, is in its capacity to operate precisely at a very high rate of speed and to follow a sequence of operations automatically. It is at this point that the limitations of the conventional mechanical desk calculator become obvious, for there is no advantage in automating computational operations beyond the rate at which the human operator can enter the data and transcribe the results. Consequently, when electronic circuitry was developed that could perform arithmetic operations at high speed, the way lay clear for the application of these techniques to computation in the earliest form of an automatic digital computer. In this field a wide variety of circuits and programming methods quickly were developed to perform automatically a wide variety of calculations. Along with this development came the need for capacity to store intermediate results. When storage units of great size were developed, the next, and most recent, problem became that of speeding the search for stored data to minimize the time required for access to stored information.

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The marvels of electronic computing have been widely publicized. By now everyone knows that multimillion dollar machines manned by skilled specialists can control the supersonic flight of a missile, handle vast quantities of business data, or even play a fair game of chess. All these things are done at speeds that are scarcely conceivable in the latest machines, which process pieces of data at rates as high as 500,000 per second.

Dramatic as they are, these and like achievements have tended to obscure a development that should be of interest to most scientists and engineers, namely, that the penetration of electronic automatic computing into the business machine market has spurred the design of small electronic automatic computers that can be used as practical tools for most research laboratories with regard to both machine capability and the cost for computations. The first impression lingers, however, and, as a result, many who might otherwise do so are not availing themselves of the advantages of electronic computing. They feel that electronic computing is suitable only for exceedingly complex mathematical situations or for very large volumes of data, that the operating cost is prohibitive, and that one must be a skilled mathematician to effectively program a computer. It is the hope of the authors that the following brief account may somewhat dispel these misconceptions. It relates how a variety of problems arising out of pyrometallurgical research were solved successfully and economically by scientists and engineers using a small electronic digital computer at the Electronic Computer Service of the Bureau of Mines, Pittsburgh, Pa.

FIELD OF RESEARCH

The work reported herein was conducted during research on pyrometallurgica processes undertaken by the Pyrometallurgy Laboratory, Bruceton, Pa. Facilitie included a blast furnace, open-hearth and electric-arc furnaces, a converter, a rotary kiln, and other experimental furnaces. The scope of research varies from the development of new processes to the evaluation of raw materials for existing processes. The types of calculations required range all the way from those involving attempts to determine complex mathematical relationships between physical quantities to those concerned with simple summaries and analyses of daily furnace production.

COMPUTING METHODS

It is clear that anyone who desires to solve a mathematical problem, even the simplest, must first comprehend a relationship in consistent terms between the facts at hand and the answer sought. He usually will know the form of relationship, either exactly, as in accounting work, or approximately, as in many scientific situations. At other times, however, the answer desired may be itself concerned with parameters relating to the form of the relationship, as in studies of field strengths (electrical, magnetic, temperature or pressure) or in statistical correlation studies. In any event, he must perceive a chain of relationships, whether parametric or not, linking the facts at hand and the answers desired. To actually undertake the solution, he must be able to conceive a specific sequence of mathematical operations, that is, a program for working out the solution. If he intends to use a desk calculator, his computing program must be reduced to the operations that this machine can perform. Ordinarily, these operations would be the arithmetic ones: Addition, subtraction, multiplication, and division, but the newer types can also extract square root. Oftentimes he will use facts that are stored in tables, mathematical quantities, such as logarithms or trigonometric functions, or perhaps values of physical properties, such as temperature equivalents or heat contents.

To delegate the computation to another would involve selecting a person who is capable of performing the operations with his own calculating device, instructing him in the specific sequence of operations to be followed, and, finally, checking on how well he followed instructions.

If it was planned to compute this case with an electronic digital computer, the preparations would be quite similar. Basically, these computers can perform only arithmetic operations. However, the more specialized machines incorporate means for preinstructing them in how to perform a variety of algebraic and analytic operations, such as extracting roots, evaluating series, and solving differential relationships. Once the programs have been devised, the machine will operate automatically upon them. Thus, electronic digital computers can be instructed in how to undertake complicated mathematical procedures, and, once learned, they are remembered as long as the program instructions are retained. In these regards it can be said that they differ from the desk calculator (and, sometimes its operator as well) in being educable to the limit of the programmer's knowledge and insight, and they remember entirely what they have been taught.

Whereas desk calculators have very limited capacity for storing intermediate values for subsequent use in the calculation program, all electronic digital computers are provided with means for storing bits of information. In the larger ones the storage capacity runs to millions of such bits, and tables, such as logarithms and specific physical properties, can be stored in tape for future use.

Speed is the principal source of their utility. It reduces the unit cost of data processing for industry and enables the scientist to solve problems that are too complex to solve analytically or too repetitious to otherwise undertake. A distinctive feature of electronic digital computers that is least publicized is the provision for checking the results of each computation.

THE ELECTRONIC DIGITAL COMPUTER AT THE BUREAU OF MINES

General Description

A Univac 60 computer is used at the Bureau of Mines Electronic Computer Service[4] (fig. 1). Information is put into this machine on punched cards,

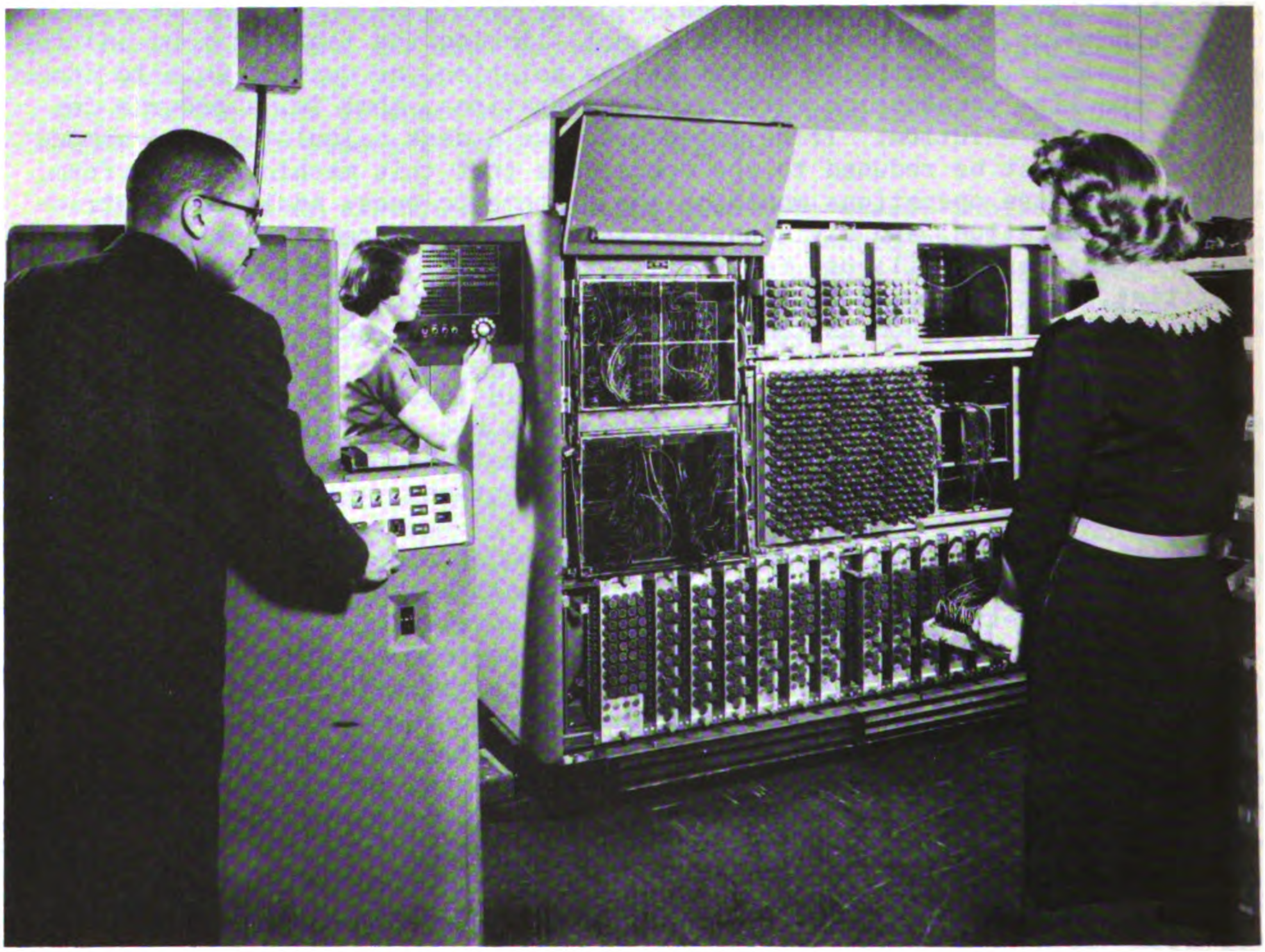

FIGURE 1. - Bureau of Mines Computer, Pittsburgh, Pa.

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[4] Subsequent to the preparation of this manuscript, this machine was replaced by a Univac 120, a computer that differs from the machine described in having twice the storage and punching capacity.

and answers are punched by it into cards. The standard Remington Rand 90-column accounting punched card (fig. 2) is used, and the necessary auxiliary equipment for handling punched cards has been provided. A small permanent staff provides the nucleus for operations.

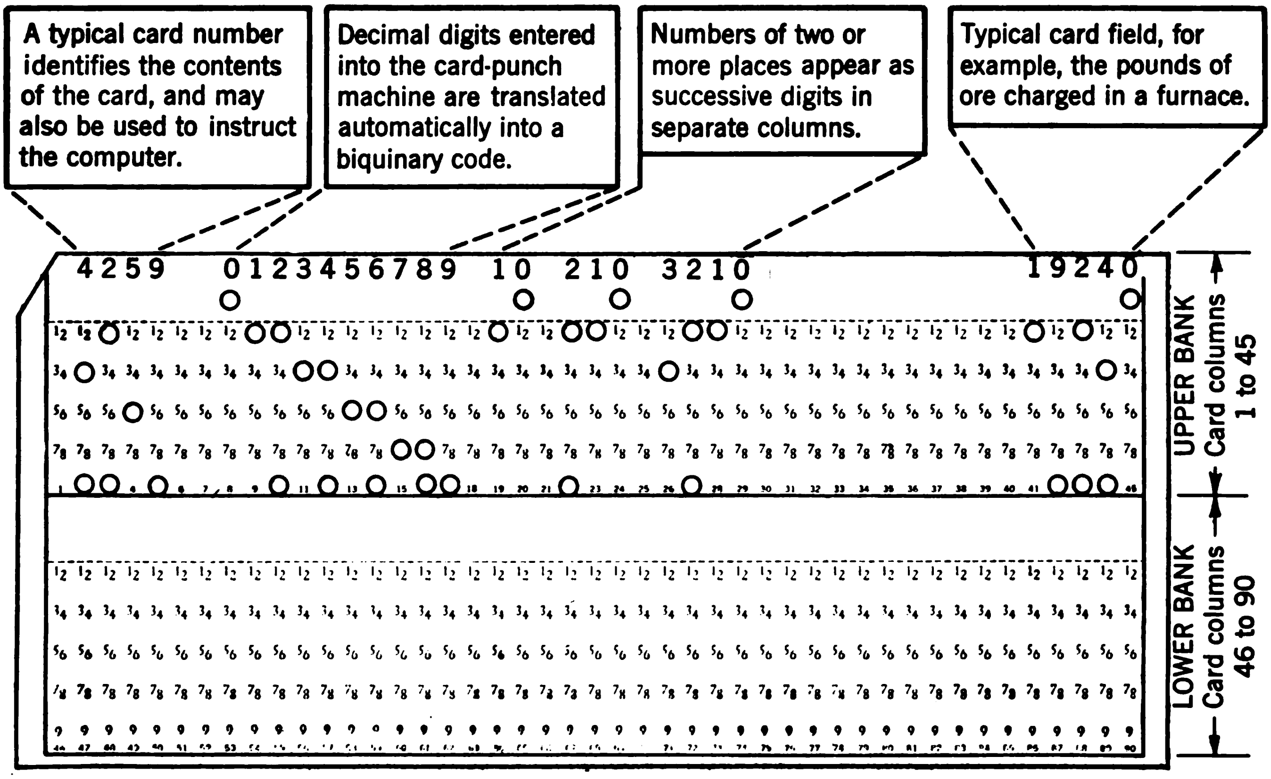
A typical card number identifies the contents of the card, and may also be used to instruct the computer.
Decimal digits entered into the card-punch machine are translated automatically into a biquinary code.
Numbers of two or more places appear as successive digits in separate columns.
Typical card field, for example, the pounds of ore charged in a furnace.
4259
0123456789
10
210
3210
19240
UPPER BANK
Card columns 1 to 45
LOWER BANK
Card columns 46 to 90

FIGURE 2. - A 90-Column Punched Card.

The Univac 60 can perform only arithmetic operations directly and on this basis is not as advanced as those desk calculators that can extract square root. However, this apparent limitation is of no practical significance, because algebraic or analytic operations that can be reduced to or approximated by a sequence of arithmetic operations may be synthesized for this machine.

This machine is designated as small because it lacks the means for storing intermediate results during a computing program. The six storage registers have a total capacity of only 60 digits. For many applications the lack of permanent storage poses no problem, since such quantities as transcendental functions or roots normally can be computed as required in a fraction of a second within a program; in other cases, tabular information can be placed in a separate deck of cards to be used as input data. By comparison to some other

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computers the 60-digit storage is equivalent in usefulness to a far larger rated storage capacity, because none of it is consumed to introduce input data or operating instructions.

The speeds of computers are difficult to compare in the abstract because the interplay of many rate factors is involved. As a general statement, however, Univac 60 operates at a relatively high speed for the computing step and a slow speed with regard to data input. If compared to desk calculator operations, its speed is of another order of magnitude. For example, a research group in the Bureau of Mines used this computer to calculate equilibrium compositions of gases resulting from fuel combustion. Each case required 5 to 10 iterations to gain a precise answer, and one iteration consumed one-half hour at a desk calculator. The research group desired to determine 1800 cases - a 4½-year job at a desk calculator. Using the computer, 30 hours of machine time was required.

The Univac 60 is particularly well designed for checking the computations performed by it. After each computational step the result is back-calculated. It must balance against the operand, or the computer will stop. Also, a very convenient panel is provided for checking out a test case beforehand.

Specific Features

Operating Units

Referring again to figure 1, the computing machine is composed of a card-sensing and punching unit, shown at the left, and the electronic computing unit, the large structure extending from the center to the right of the picture. These two units are connected by electrical cables. The two removable, externally-wired connection panels are visible in the center of the picture where they can be seen mounted vertically on the side of the computing unit.

The punched cards are placed in a feeding magazine in the sensing-punching unit, and then are fed automatically into the sensing section where electrical pulses corresponding to the location of punched holes in the card are transmitted to the computing unit. If an answer is to be punched into the card, this will take place in the punching section of this unit during the next card cycle, that is, while the following card from the deck is being sensed for computation, the answers from the preceding computation are being punched into the first card. This unit of the computer also contains the control panel, which is visible in figure 1 at the right hand of the operator in the left foreground. In normal operation only one switch on this panel need be turned on, the one that starts the card feeding machinery; at the end of the run the machine shuts off automatically. All information relative to the specific program is contained in the wiring of the connection panels and, if desired, in control punching from the cards themselves. Once a program has been devised and checked, it can be reconstituted in the minute or so that it takes to place the connection panels in the computing unit, regardless of how complicated the computing pattern may be.

The operator in the background is preparing to dial the next step during her check of the program that is in the machine. The facility with which a test case can be checked through step-by-step on this checking panel is invaluable, particularly where a program of complex operations is being set up for a short run of data. Using this panel, the operator can advance step-by-step through the entire program identifying at each step the arithmetic process used, the variables and the storage registers involved and their arithmetic values, the signs and decimal locations of these quantities, the sign of the result, and whether the step checks.

Communication of Instructions and Data

The Univac 60 operates, as stated, upon 90-column punched cards containing one digit of information in each column.[5] Related columns of digits can be linked together and fed into the computing program as a factor, termed an element. If desired, specific instructions to the machine for a card may be prepunched in coded digit form to modify the computational pattern through selection of alternative elements.

The principal source of instructions for the computational program is a set of two externally-wired connection panels. The input-output panel is the lower panel shown in figure 1. It is the means of connecting information sensed from the punched holes in the card to the computing unit as digits. On this panel related columns of digits are grouped together to form elements for use in computational operations. For example, if information concerning the weight of ore was punched in columns 41 through 45 (fig. 2), the digits sensed in these columns would be transmitted through the input-output panel to the computing unit as a group for computation. Figure 3 shows sample input wiring for these card columns (designated here as F40 for card field 40). Information punched in the cards also is connected through this panel to the computing unit for controlling details of the computational operation by selecting devices that depend upon the presence or absence of a control punch in the card. This panel also connects the storage registers to the punching dies for punching answers in appropriate card columns.

The upper, or constant-program, panel in figure 1 performs four major functions by external wiring. First, it provides the means for wiring constant values into the program as elements from a bank of digit-emitting circuits within the machine (fig. 4). Second, the basic sequence of operations and all alternatives that are required for contingencies are established on this panel (fig. 5). Third, instructions regarding the content of each computational step are given here (fig. 5). Fourth, decimal point locations within each element and storage register are set up on this panel (fig. 4).

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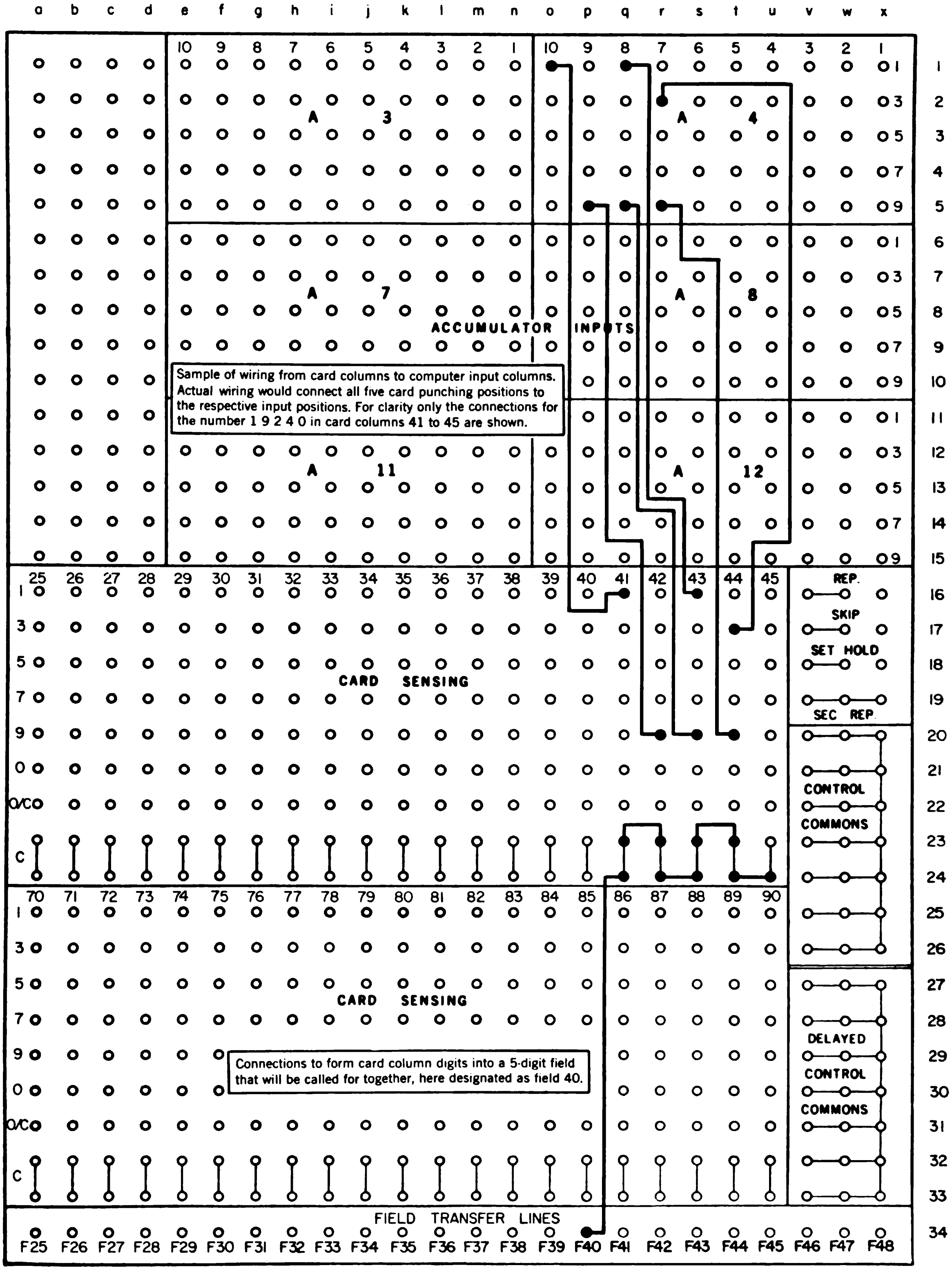
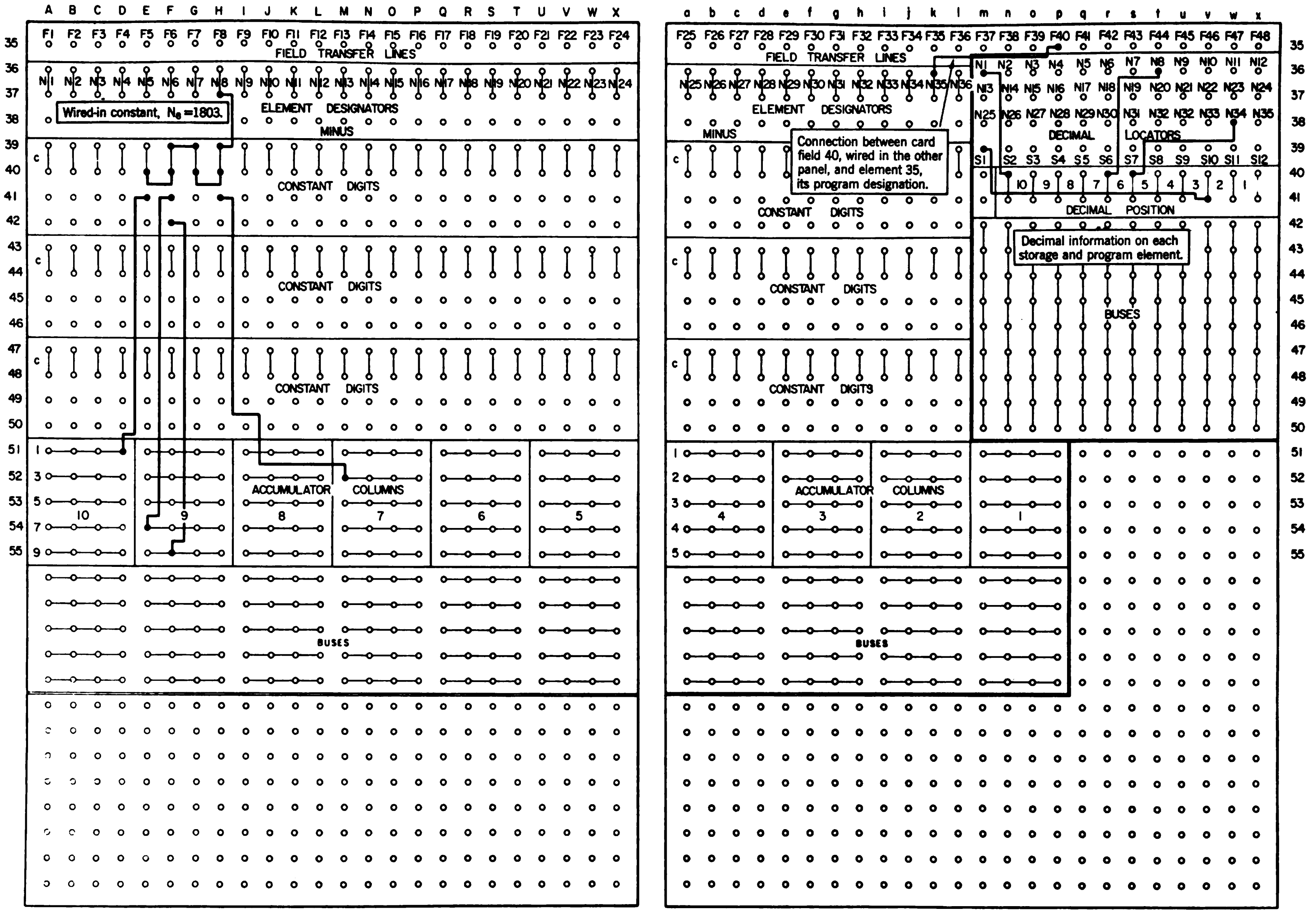
[5] This machine also can respond to alphabetical information for control purposes and can reproduce such information, but alphabetical operations will not be discussed. It will not compute alphabetical data.



Sample of wiring from card columns to computer input columns. Actual wiring would connect all five card punching positions to the respective input positions. For clarity only the connections for the number 1 9 2 4 0 in card columns 41 to 45 are shown.

Connections to form card column digits into a 5-digit field that will be called for together, here designated as field 40.

FIGURE 3. - Sample Input Wiring for Card-Sensed Data.



Wired-in constant, $N_8 = 1803$.

Connection between card field 40, wired in the other panel, and element 35, its program designation.

Decimal information on each storage and program element.

FIGURE 4. - Sample Input Wiring for Constant Digits, Decimal Locations and Card Field Connections.

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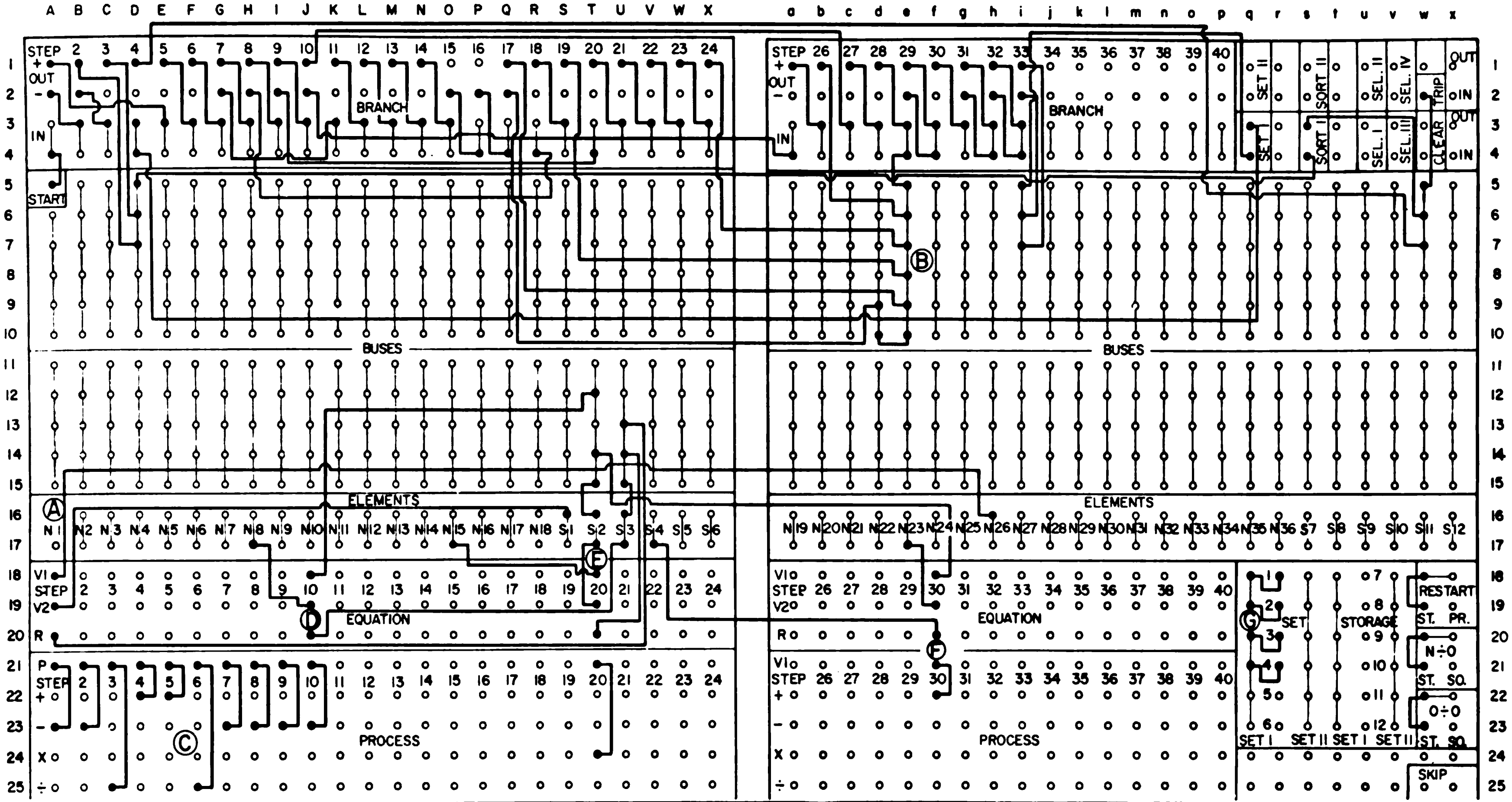

LEGEND

Ⓐ Sample wiring for step 1
Value 1 — Element N26
Process — Subtract
Value 2 — Storage 1
Result to — Storage 3

Ⓑ All five subprograms for different states are fed into step 29 through bussed connections.

Ⓒ Wiring for the arithmetic processes used in steps 1-10.

Ⓓ Wiring for step 10

Ⓔ Wiring for step 20

Ⓕ Wiring for step 30

Ⓖ Stored answers in storages 1, 2, 3, and 4 will be set for punching when "set 1" is reached after step 33.

Complete step wiring for heat content program. Compare with "next step" listing in Figure 6.

FIGURE 5. - Sample Wiring for a Sequence of Program Steps and Step Computations.

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Output

The answers developed are punched in either the same card bearing the input data or a following card. Since the answers come from the storage registers, a maximum of six 10-digit numbers can be punched.

Capacity and Speed

All 90 columns of the punched card are sensed and any 60 columns may be used for computational data. These 60 digits may be divided into a maximum of 36 elements. The number of digits in an element can vary from 1 to 10, but the total number of digits for all elements cannot exceed 60. As many as 36 constant elements, each one variable from 1 to 10 digits in size, can be emitted internally, but the total of constant and card-sensed elements may not exceed 36. That is, whether an element originates as a variable from a card or a constant within the machine, the number of elements that may be employed in the computational sequence is limited to 36 unless selection of alternative elements is undertaken during the computational program. The decimal point for each element is wired externally through the connection panel to decimalize the result of each computational step. Through use of selectors the decimal locations can be varied as needed.

The result of each computational operation is usually directed to a storage register where it remains available for recall as often as needed. When a result is directed into a storage register, the previous content of that register is erased. A register that supplies a value for a computational step cannot receive the result of that step. Each storage register has a capacity of 10 digits and sign and is decimalized.

Each computational step, and there are a total of 40 available, involves one arithmetic operation of values of one element or stored quantity upon another, routing the result to a storage register, and directing the computer to the next step. For example, the addition of 3 numbers would require two steps:

Step 1: $N1 + N2 = R1$
Step 2: $R1 + N3 = R2$

The same value may be used as both operator and operand in a step whether this value comes from storage, the card, or is a machine-emitted constant.

Each step calculation is performed at the following average rates: Addition or subtraction, 100 per second, multiplication or division, 20 per second. Each step is performed sequentially so that the total computing time is the sum of the respective times required for the step computations.

The minimum time requirement for computation is limited by the rate at which cards can be fed. The machine will feed cards at a constant rate of 150 per minute. Out of this residence time of 400 milleseconds, 75 milleseconds are required for feeding, sensing, and punching the card, and 325 remain for calculation. If the calculation requires more than 325 milleseconds, the computer automatically waits until the signal at the end of the calculation has been given before punching, feeding and sensing the next card.

Decision Functions

The provisions for decision-making that are incorporated in an electronic computer provide at once its greatest asset for scientific calculation while forming the deepest trap for the unwary programmer. These machines are intractably logical (in the pattern, anyway, of the logic in their design) and make no allowance for any unforeseen failures to provide an instruction for action in each decision situation that arises. Fortunately, an aptitude for thinking in patterns of mathematical logic is characteristic of scientists, so that once the logic pattern and limitations of a particular computer have been learned, the scientist experiences only occasional difficulties in this regard.

The Univac 60 has two types of built-in functions for making "yes-no" decisions, branching and selection. Branching is the term applied to the alternative routing that exists for the progress of the computer program from each step depending on whether the result of the step computation was positive or negative. A zero result is always considered positive. The other decision function, selection, allows a choice of alternative operating instructions depending upon a wired-in instruction, the presence or absence of a control signal from a control instruction punched in the card, or the plus or minus branching of a step. There are 36 selectors for selecting a total of 96 alternatives.

It is difficult to describe adequately the importance of these decision functions in the abstract. Perhaps their value will become evident in the descriptions of the specific problems below. It is sufficient for now to state that this type of function really separates electronic digital computers from desk calculators in a fundamental sense.

Auxiliary Card Handling Equipment

The computer, as indicated earlier, senses information in the form of holes in cards and supplies its answers in the same form. Consequently, a certain amount of auxiliary card handling machinery is required to translate the input information, supplied as ordinary decimal digits, into punched-hole language that can be communicated to the computer. To make the results meaningful, some means also must be provided for translating the results from punched-hole notation back to decimalized numbers. This need for translation machinery is inherent to the punched card method. Although this computer uses the standard Remington Rand punched card notation, it typifies the situation for computers that use other types of coded data, for the punched cards indicate values by a non-decimal system of numeration known as biquinary. It is related to Roman numeration. Table 1 compares the numerational representations of the first 10 numbers in the decimal, Remington Rand biquinary, Roman biquinary, and, for information, the binary system. The latter system is widely used in computers for performing the actual computations.

TABLE 1. - Comparative representation of the first 10 cardinal numbers in decimal and biquinary numerations

(Binary numeration included for information)

Cardinal number	Decimal	Remington Rand punched card biquinary		Roman biquinary		Binary
		Card rows punched	Numeric code	Roman designation	Numeric code	Numeric code
zero	0	-	00	-	00	0
one	1	1	01	I	01	1
two	2	9,1	11	II	02	10
three	3	3	02	III	03	11
four	4	9,3	12	IIII[1]	04	100
five	5	5	03	V	10	101
six	6	9,5	13	VI	11	110
seven	7	7	04	VII	12	111
eight	8	9,7	14	VIII	13	1000
nine	9	9	10	VIIII[1]	14	1001

[1] This is true Roman numeration. It is the authors' understanding that the subtractive form, for example IV, was not adopted until the 16th century.

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The array of machines at the computing center is typical of a punched card installation. There are several verifying keypunch machines, for punching the cards and then repunching them to verify the original punching, and a mechanical verifier to detect punching errors. These are the machines that translate information into punched card language. Equipment for retranslating includes a machine known as an interpreter that prints decimal numerals on the punched card corresponding to the information punched in it, and tabulating machines to prepare listings on paper tape of the information contained in punched form on the cards. Two other types of machines are used for marshalling data in punched card form. There are sorters, which assemble cards in the desired order, and a collating reproducer (a marvelous machine in its own right) that will reproduce cards, compare the content of cards from two supposedly identical decks, or interfile two decks of cards in proper order. All of these machines are used at some stage in either preparing the cards for calculation or printing a record of the answers obtained.

Computing Center Personnel

The Electronic Computer Service is staffed by two mathematicians and three machine operators. This group provides the nucleus for operations, and can undertake all of the work necessary to provide a complete set of calculations.

Programming

This is a process which translates relationships from the logical and mathematical language of the scientist into instructions phrased in the language of the machine and provides for orderly and unambiguous communication between them.

Research personnel are encouraged to participate in programming. Typically, they discuss their problem with the mathematicians on the staff of the computing center and decide upon the features of the computing program. The machine operators prepare the cards. Meanwhile, the research personnel furnish information for the development of the program in detail. As questions arise, and they invariably do, one of the mathematicians is consulted. When the program is complicated, it may be checked on the computer by the research men. It is at this stage in the development of a program that the facility for running a test case by means of the checking panel on the computing unit is very useful. Experience has shown that a brief consultation with the computer specialist will often resolve in a few minutes any difficulty that may have arisen in the construction of the program.

In many installations this work is performed only by an experienced specialist, but the authors have found from their experience with this computer that a man with a logical mind can program some of his own problems after surprisingly little training. Since very few problems are simple enough to be completely understood in terms of machine language beforehand, adjustments usually must be made to the initial program.

PROBLEMS AND TYPICAL SOLUTIONS

Classes of Problems

In the processing of either scientific or business data those problems that are suitable for computer solution may be divided into two broad classes:

1. Problems that require performance of the same calculation pattern on a large number of data.

2. Problems that require very long, complex or iterative processes for their solution.

In the following sections each of these classes will be discussed and illustrated by examples of problems that have been solved effectively and economically using the computing facilities described above.

Examples of Problems

Class I. Problems of a Repetitive Nature

Scope

This class of problem usually involves a large number of small groups of data on each of which a limited number of simple calculations are to be performed. The relationships between the variables are predetermined and usually are arithmetic. General accounting procedures such as payroll, inventory, and statements of income and expenditures fall into this category. The problems described herein exemplify this class of problem in scientific work.

A. Tabulations of Thermodynamic Properties

One of the earlier problems posed by the Pyrometallurgy Laboratory was that of calculating the heat content of pure iron at intervals of 5° F. over the range of 0° - 3000° F., taking account of the phase changes and change of state that occurred. Estimating equations relating temperatures in degrees Kelvin to heat content in calories per gram-mole had been published by Kelley[6] as follows:

Fe(α), 298 to 1,033°K (extrapolated to 273°K for this table)

$$H_T - H_{298.16} = 3.37T + 3.55\times10^{-3}T^2 - 0.43\times10^{5}T^{-1} - 1,176$$

Fe(β), 1,033 to 1,179°K

$$H_T - H_{298.16} = 10.40T - 4,280$$

Fe(γ), 1,179 to 1,674°K

$$H_T - H_{298.16} = 4.85T + 1.50\times10^{-3}T^2 + 390$$

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[6] Kelley, K. K. Contributions to the Data on Theoretical Metallurgy. X. High-temperature Heat-content, Heat-capacity and Entropy Data for Inorganic Compounds: Bureau of Mines Bull. 476, 1949, p. 86.

Fe(δ), 1,674 to 1,803°K

$$H_T - H_{298.16} = 10.30T - 4,420$$

Fe(liq.) 1,803 to 1,900°K (extrapolated to 1,922°K for this table)

$$H_T - H_{298.16} = 10.00T - 180$$

Although each calculation was simple, the problem nonetheless was to undertake 601 sets of calculations involving transformations of integral values of Fahrenheit temperature to fractional values of Kelvin temperature, selecting the proper equation for the temperature, calculating the answer, and finally expressing it in B.t.u. per pound instead of calories per mole. It was decided that this problem was suitable for computer solution.

The program for this problem was unusual since no data were fed to the computer. The computer calculated the heat content of iron at 0° F. and punched out this temperature value and the results into a blank card. It then was instructed to increase by 5° F. the value of temperature that had been stored from the first card and to proceed with the heat content calculation corresponding to that new temperature level. By continuing in this manner the computer created its own data internally and stopped computing only when the value of temperature in its memory reached 3,005° F. This technique of internal data creation eliminated completely the cost of preparing any cards for the computer.

The time required to program and compute the entire deck was:

Metallurgical technologist	1 day
Computer specialist	2 hours
Computer time:	
To check test case	1/2 hour
To compute 601 values	12 minutes

Overall, the time saving was 80 percent; the table was prepared in 1 day, instead of 6 days at a desk calculator; and the cost saving was 55 percent when compared to the cost for a clerk operating a calculator. Most important, an error-free tabulation was obtained in two useful forms: A legibly printed tape for desk reference, and a deck of cards that could be used as a source of heat content data for subsequent work.

The original program for this work is given in figure 6 as a concrete example of how a simple computer program was worked out. Figure 5 shows samples of the step and computation wiring, and figure 7 presents a sample calculation.

The notes on the program sheet for the most part are self-explanatory. The upper section, headed "Table of Factors" provides space for listing the 36 permissible elements; in this instance no information was read into the computer from the cards. and all 27 constants were developed within the machine. The center table provides space for identifying each step and the next step to be followed. Notice how the steps can be used in any order. At the bottom,

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PROGRAM CHART NO. **Met 4**
APPLICATION: **Enthalpy of Iron**

UNIVAC 60 & 120
PUNCHED-CARD ELECTRONIC COMPUTERS

TABLE OF FACTORS

SYM	SIGN	CARD NO.	CARD FIELD TITLE OR CONSTANT VALUE	SYM	SIGN	CARD NO.	CARD FIELD TITLE OR CONSTANT VALUE	SYM	SIGN	CARD NO.	CARD FIELD TITLE OR CONSTANT VALUE
N1	+		Zero	N13	+		10.40 a_2	N25	+		55.85 Factor – mol. wt. of iron
N2	+		5.	N14	–		4,280. d_2	N26	+		3,000. Limit – stop computing on next card
N3	+		460. Constant – °R = °F + 460	N15	+		4.85 a_3	N27	+		3,005. Limit – stop machine on next card
N4	+		1.8 Factor – °K = R° ÷ 1.8	N16	+		0.00150 b_3	N28			
N5	+		1,033. Critical temp $\alpha \rightarrow \beta$	N17	+		390. d_3	N29			
N6	+		1,179. Critical temp $\beta \rightarrow \gamma$	N18	+		10.30 a_4	N30			
N7	+		1,674. Critical temp $\gamma \rightarrow \delta$	N19	–		4,420. d_4	N31			
N8	+		1,803. Critical temp $\delta \rightarrow$ liq.	N20	+		10. a_5	N32			
N9	+		3.37 a_1	N21	–		180. d_5	N33			
N10	+		0.00355 b_1	N22	+		1.8 Factor – Btu. = cal ÷ 1.8	N34			
N11	–		43,000. c_1	N23	+		0.05 Round-off to 0.1	N35			
N12	–		1,176. d_1	N24	+		0.5 Round-off to 1.0	N36			

CARD DESCRIPTION Blank card

STEP NO.	CARD NO.	VALUE 1 DESCRIPTION	SIGN	SYM	PROCESS	VALUE 2 DESCRIPTION	SIGN	SYM	RESULT DESCRIPTION	SIGN	SYM	S1 3/2	S2 4/3	S3 6/5	S4 6/5	S5 6/5	S6 5/4	S7	S8	S9	S10	S11	S12	NEXT STEP –	NEXT STEP +
1		3,000	+	N_{26}	–	Temp., °F. [Tn]	+	S_1	Tn ≤ 3,000 = +, to compute Tn > 3,000 = –, not computed	±	S_3		1	When Tn exceeds 3000° F. this										2	5
2		3,005	+	N_{27}	–	Tn	+	S_1	Tn ≤ 3,005 = + sort card Tn > 3,005 = – stop machine	±	S_3			sequence will pass the cards to										3	Sort 1
3		Zero	+	N_1	÷	Zero	+	N_1	0÷0, machine set to stop		S_3			another hopper & will stop the machine.											Sort 1
4		Tn+1. °F.	+	S_5	+	Zero	+	N_1	Tn+1 in °F., for next card	+	S_1	Save		10	Transfer temperature reading to storage for holding.										Trip
5		Tn, °F.	+	S_1	+	460.	+	N_3	Tn in °R.	+	S_3				2	Transform temperature to									6
6		Tn, °R.	+	S_3	÷	1.8	+	N_4	Tn in °K.	+	S_2		Save			Kelvin scale.									7
7		Tn, °K.	+	S_2	–	1,033. ($T\alpha-\beta$)	+	N_5	Neg. if Tn < T $\alpha-\beta$	±	S_3													11	8
8		Tn, °K.	+	S_2	–	1,179. ($T\beta-\gamma$)	+	N_6	Neg. if Tn < T $\beta-\gamma$	±	S_3				3	Determine proper crystal								18	9
9		Tn, °K.	+	S_2	–	1,674. ($T\gamma-\delta$)	+	N_7	Neg. if Tn < T $\gamma-\delta$	±	S_3					form and state by branching.								20	10
10		Tn, °K.	+	S_2	–	1,803. ($T\delta-$liq.)	+	N_8	Neg. if Tn < T $\delta-$liq. Pos. if Tn > T $\delta-$liq.	±	S_3													25	27
11		3.37 (a_1)	+	N_9	x	(T)	+	S_2	(a_1T)	+	S_3														12
12		.00355 (b_1)	+	N_{10}	x	(T)	+	S_2	(b_1T)	+	S_4														13
13		(b_1T)	+	S_4	x	(T)	+	S_2	(b_1T^2)	+	S_5														14
14		(a_1T)	+	S_3	+	(b_1T^2)	+	S_5	($a_1T + b_1T^2$)	+	S_6				4	α-region									15
15		43,000. (c_1)	–	N_{11}	÷	(T)	+	S_2	(c_1T^{-1})	–	S_3													16	
16		(c_1T^{-1})	–	S_3	+	1,176. (d_1)	–	N_{12}	($c_1T^{-1} + d$)	–	S_4													17	
17		($a_1T + bT^2$)	+	S_6	+	($cT^{-1} + d$)	–	S_4	($a_1T + b_1T^2 + c_1T^{-1} + d_1$) = H_T	±	S_5													29	29
18		10.40 (a_2)	+	N_{13}	x	(T)	+	S_2	(a_2T)	+	S_3				5	β-region									19
19		(a_2T)	+	S_3	+	4,280. (d_2)	–	N_{14}	($a_2T + d_2$) = H_T	+	S_5														29
20		4.85 (a_3)	+	N_{15}	x	(T)	+	S_2	(a_3T)	+	S_3														21
21		.00150 (b_3)	+	N_{16}	x	(T)	+	S_2	(b_3T)	+	S_4														22
22		(b_3T)	+	S_4	x	(T)	+	S_2	(b_3T^2)	+	S_5				6	γ-region									23
23		(a_3T)	+	S_3	+	(b_3T^2)	+	S_5	($a_3T + b_3T^2$)	+	S_6														24
24		($a_3T + b_3T^2$)	+	S_6	+	390. (d_3)	+	N_{17}	($a_3T + b_3T^2 + d_3$) = H_T	+	S_5														29
25		10.30 (a_4)	+	N_{18}	x	(T)	+	S_2	(a_4T)	+	S_3				7	δ-region									26
26		(a_4T)	+	S_3	+	4,420. (d_4)	–	N_{19}	($a_4T + d_4$) = H_T	+	S_5														29
27		10. (a_5)	+	N_{20}	x	(T)	+	S_2	(a_5T)	+	S_3														28
28		(a_5T)	+	S_3	+	180. (d_5)	–	N_{21}	($a_5T + d_5$) = H_T	+	S_5				8	Liquid state									29
29		Ht, cal/mole	±	S_5	x	1.8	+	N_{22}	H_T, Btu/lb-mole	±	S_3													30	30
30		Tn, °K.	+	S_2	+	0.05 Roundoff	+	N_{23}	Tn, °K, to nearest 0.1	+	S_4		↓		Save										31
31		Ht, Btu./lb. mole	±	S_3	+	0.5 Roundoff	+	N_{24}	H_T, Btu/mole, to nearest 1.0	±	S_2		Save											32	32
32		Ht, Btu./lb. mole	±	S_3	÷	55.85	+	N_{25}	H_T, Btu/lb.	±	S_6	↓	↓		↓									33	33
33		Ht, Btu./lb.	±	S_6	+	0.05 Roundoff	+	N_{23}	H_T, Btu/lb., to nearest 0.1	±	S_3	X	X	X	X									Set 1	Set 1
34		Tn, °F.	+	S_1	+	5° F.	+	N_2	Tn+1, °F, for next card	+	S_5			9	Temperature for next card										4
35																									
36																									
37																									
38																									
39																									
40																									

SYM	CARD FIELD TITLE	NEG. COL	NEG. POS	OUTPUT PUNCHING 10	9	8	7	6	5	4	3	2	1	DEC LOC	SET 1	SET 2	CLEAR	SYM
s1	Temperature – °F.							x	x	x	x			3/2	x			s1
s2	Btu per lb.-mole	90	5		x	x	x	x	x	x				4/3	x		x	s2
s3	Btu per lb.	90	5	x	x	x	x	x	x					6/5	x		x	s3
s4	Temperature – °K.				x	x	x	x	x					6/5	x		x	s4
s5																	x	s5
s6																	x	s6
s7																		s7
s8																		s8
s9																		s9
s10																		s10
s11																		s11
s12																		s12

FROM	TO
START	Step 1
SET 1	Step 34
SET 2	
SORT 1	Trip
SORT 2	
CLEAR	
P.S. I	
P.S. II	
P.S. III	
P.S. IV	

REPRODUCE CONTROLS	COL.	POS.
REP		
SKIP		
SET HOLD		
SEC REP		

	0 ÷ 0	N ÷ 0
STOP	x	x
SORT		

RESTART	
STEP	x
PROGRAM	

FIGURE 6. - Program Chart for Computing the Enthalpy of Iron.

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PLANNING CHART NO.: *MET. 4*

APPLICATION: *ENTHALPY OF IRON, T=2200° F.*

PUNCHED-CARD ELECTRONIC COMPUTERS

LINE NO.	STEP NO.	CALCULATION VALUE 1	SYM	PROCESS	VALUE 2	SYM	RESULT S1 3/2	S2 4/3	S3 6/5	S4 6/5	S5 6/5	S6 5/4	NEXT STEP −	+
							10 9 8 7 6 5 4 3 2 1	10 9 8 7 6 5 4 3 2 1	10 9 8 7 6 5 4 3 2 1	10 9 8 7 6 5 4 3 2 1	10 9 8 7 6 5 4 3 2 1	10 9 8 7 6 5 4 3 2 1	−	+
1	1	3000.	N_{26}	−	2200.	S_1	2200		800				2	5
2	5	2200.	S_1	+	460.	N_3			2660					6
3	6	2660.	S_3	÷	1.8	N_4		1477777						7
4	7	1477.777	S_2	−	1033.	N_5			+ 444777					8
5	8	1477.777	S_2	−	1179.	N_6			+ 298777					9
6	9	1477.777	S_2	−	1674.	N_7			− 196223				20	10
7	20	4.85	N_{15}	×	1477.777	S_2			716722184					21
8	21	0.00150	N_{16}	×	1477.777	S_2				221666				22
9	22	2.21666	S_4	×	1477.777	S_2					327475538			23
10	23	7167.22184	S_3	+	3274.75538	S_5						104419772		24
11	24	10441.9772	S_6	+	390.	N_{17}					1 08319772			29
12	29	10831.9772	S_5	×	1.8	N_{22}			1 949755899				30	30
13	30	1477.777	S_2	+	0.05	N_{23}				1477827				31
14	31	19497.55899	S_3	+	0.5	N_{24}		19498058					32	32
15	32	19497.55899	S_3	÷	55.85	N_{25}						3941058	33	33
16	33	394.1058	S_6	+	0.05	N_{23}			3941558				Set 1	Set 1
17	Set	1 to Step 34												
18	34	2200.	S_1	+	5.	N_2					2205			4
19	4	2205.	S_5	+	ZERO	N_1	2205							TRIP
		OUTPUT PUNCHED					2200	19498	3941	14778				
		HELD FOR NEXT CARD					2205							
24														
25														
26														
27														
28														

FIGURE 7. - Sample Computation of the Enthalpy of Iron.

space is set aside for specifying which information is to be punched into the cards, and, in the lower right corner, for designation of certain operating functions.

Starting with a deck of blank cards and a cleared machine, the first card was calculated (beginning at step 5) for 0° F. from a machine-fed value of zero. Next, 5° F. was added to the temperature (step 34) and the result was placed (step 4) in storage register No. 1 (S_1) for use with the next card. Use of branching to select the proper equation of state by reference to established temperature limits is seen in steps 7 through 10. The operation in steps 30, 31, and 33 rounded off the answer in the final decimal place; it simply added 5 to the place to the right of the digit to be rounded, and if the digit in that place was already 5 or higher, the addition of 5 more carried over 1 to the round-off column. After the step 33, four storage units, S_1, S_2, S_3, and S_4 were set for punching the answers desired. The machine was routed to Set I, the signal that set the punching dies, then to steps 34 and 4 to establish a temperature 5° F. higher for the next card, and finally to Trip, the operation that discharged the card from the machine. The next card was fed automatically and the cycle started anew. The arrangements for halting the calculations after the 3000° F. data were punched are shown in steps 1-3. The machine was not stopped until the second cycle after this temperature to allow time for the last card calculated to be punched and fed into the receiving hopper. By using a sorting instruction, Sort I, these last two cards were segregated in a separate receiving hopper.

B. Periodic Analyses of Experimental Blast Furnace Operations

A major project of the Pyrometallurgical Laboratory is concerned with research upon ironmaking in a 4-foot hearth blast furnace.7/ The project supervision was faced with a formidable problem in analyzing the results of operations for both daily and nondaily periods of particular interest because so many variables had to be considered.

A system for processing these data through the computer has been developed and placed in operation at the computing center in Pittsburgh. It included the design of new data forms suitable for fast, accurate card punching without any intermediate transcription of operational data.

This computer program handles not only a large volume of data, but a wide variety of data items and results as well. It has a capacity of 46 items of input data read by the computer from 9 different card forms and an output of 48 summary results. The calculations desired were found to be adaptable to machine computation since there was considerable similarity in the methods used to reach the various results. Among the 48 output items are 10 arithmetic averages, 10 weighted averages, 21 cumulative totals, and 7 ratios. Owing to the similarities referred to above, these results were accomplished in a program of only 60 arithmetic steps (the summary cards are passed through the computer twice).

7/ Bosley, J. J., Jr., and Royer, M. B., Results of Operations with an Experimental Blast Furnace: Blast Furnace, Coke Oven and Raw Materials Proc., AIME, vol. 17, 1958, pp. 256-263.

The program includes provisions by which the computer may compensate for missing data, such as chemical compositions of metal or slag. It "recognizes" which data items each card contains and then proceeds to select the program tailored to the type of data in the card from one of six programs that have been designed to encompass all of the computing patterns required. When the computer recognizes a summary card, that is, a card for answers, it selects the proper summarizing program from four that have been prepared for computing and punching the desired results, using the information accumulated from the preceding detail cards.

A major advantage of this type of program is that summaries of operations may be made on any number of arbitrary intervals within a particular time span of furnace operations. A summary for such an interval can be accomplished simply by inserting summary cards at the desired places in the original deck of detail cards, and then feeding these cards to the computer. A typical summary is shown in table 2. Currently, summaries are being obtained for two concurrent divisions of time, by day, and by periods of constant operating conditions (burden ratio or blast rate). The number and variety of these time divisions can be altered or extended as conditions change without any alteration to the existing program other than changing the location of the summary cards in the decks of cards.

A second advantage is that all operational decisions are made by the computer, so that a minimum of effort and time is required of the computer operator. Such a routine pattern is highly desirable for data processing because it makes results available as quickly as possible with assured accuracy and orderly presentation.

The entire daily summary is prepared and tabulated in less than 2 hours by one machine operator, and fully one-half of this time is consumed in punching the cards, which average about 120 per day. A summary for a period of operations embracing portions of days is prepared in less than 1 hour from the detail cards that have been punched previously for the daily summaries. Contrast this with an everage of six hours' work by an experienced employee using an automatic desk calculator to make a daily summary and a like chore for each period summary desired. Not only has the actual cost for a summary been reduced to one-quarter of the cost when using a desk calculator, but a skilled technician has been freed for creative work, and all of the data remain readily available for further investigation.

Class II. Problems Involving Complex or Iterative Calculations

Scope

Problems of this second type are those which are extremely difficult for desk calculation. Relationships are usually algebraic. At times an analytical solution seems hopelessly complex, so resort must be had to a numerical approximation which itself may be exceedingly lengthy. Typical operations of this character include the evaluation of a series to a specified convergence interval or the solution of partial differential equations or higher rank matrices. In the latter case, interest lies in determining precisely small differences between very large numbers. Machine computing is appropriate for such problems even though only a few cases may be presented for solution. In fact, such problems are characterized by relatively small groups of input data that are to be operated upon in a large number of intermediate calculations which often are repeated in cyclic fashion. The computer need only be given the instructions for one cycle, a means of looking back to its start, and criteria for deciding when the results of the desired precision have been reached. Of course there is usually a much more sophisticated mathematical background in the nature of such problems compared to those of the first class discussed, but this is no cause for concern, for these problems only arise from the work of scientists who are themselves mathematically inclined. At times, difficulty may be experienced in reducing such problems to a routine of permissible instructions within the limitations of the computer. It is at this point that the computer specialist must probe his resources: Personal experience, published references, and innate ability, principally the latter.

A. Unsteady State Heat Losses to Furnace Walls

A problem of this type was posed when it was desired to evaluate the heat losses to the walls of a preheater furnace that was being developed. Temperature readings at selected locations within the walls had been recorded at various times after the start of heating, and the approximate temperatures on the interior wall also were known. To calculate the heat losses to the furnace walls at each location, it was necessary to approximate closely the temperature-time curve for each location by a simple power series in time. In terms of heat transfer theory, a solution of the Fourier equation was desired for unsteady heat flow through a wall where the hot-face temperature was increasing with time and position.

Curve fitting was accomplished by the Method of Least Squares. This method is familiar to many from experience in fitting a linear curve to data. In this instance, however, the fit was to be made to a power series because the temperature data were plainly curvilinear with respect to time. This type of problem is extremely tedious by hand methods of calculations. First, a reasonable choice must be made of the number of terms needed. If the series chosen is of the "nth" order, the solution involves creating (n+1) simultaneous equations from the coordinates of the known points and solving these for the (n+1) coefficients of the terms in the series.

A similar problem had already been programmed by the Computing Center for another research group within the Bureau of Mines, so that with only minor modifications the desired curve fitting was accomplished.

From the empirical equations that were developed relating heat losses to the temperatures in the interior of the walls and the physical properties of the wall materials, accurate predictions of the wall temperatures could be made. The result was a relationship that required only a knowledge of the furnace temperature and wall conductivity (both factors being known by a designer) and was accurate enough to use in predicting heat losses to the walls of similar furnaces that might be designed. Without a computer this problem probably would not have been tackled.

TABLE 2. - Typical daily summary of experimental blast furnace operations

```
40781   DATE CAMP PERBL HEAT  START     START                             TOTAL   BLAST
40782 MODYYR NO   NO BL HEAT  TIME        DAY                             HOURS    TEMP
4078  120558 11               2255         16                              2400    1880

41041   DATE CAMP PER  METAL                      METAL    PROD     PCT     PCT           METAL
41042 MODYYR NO   NO   METAL                       TEMP    RATE      SI       S          WEIGHT
4104  120558 11                                    2432    1901     112      89           45636

42591   DATE CAMP PER    COKE                    WEIGHT                   TOTAL    COKE   TOTAL
42592 MODYYR NO   NO     COKE                      COKE                    COKE    RATE  ROUNDS
4259  120558 11                                   34000                   34000    1490     136

43021   DATE CAMP PER SLAG A                       SLAG    SLAG     PCT     PCT            SLAG
43022 MODYYR NO   NO  SLAG A                       TEMP    RATE    SIO2      FE          WEIGHT
4302  120558 11                                    2661     998    3691      52           22810

44011   DATE CAMP PER SLAG B                        PCT     PCT     PCT     PCT     PCT      NO
44012 MODYYR NO   NO  SLAG B                          S      MN   AL2O3     C2O     MGO    TAPS
4401  120558 11                                      79      10    1321    3377    1153      12

45791   DATE CAMP PER    WIND START     START     RATIO   RATIO           TOTAL BLOWING
45792 MODYYR NO   NO     WIND TIME        DAY         A       B           HOURS    RATE
4579  120558 11               2255         16       122      90            2400    1190

47191   DATE CAMP PER    ORES                       ORE     ORE     ORE     ORE  BURDEN     ALL
47192 MODYYR NO   NO     ORES                         A       B       C       D   RATIO    ORES
4719  120558 11                                   44064   33048            6120     244   83232

48391   DATE CAMP PER FLUXES                       FLUX    FLUX    FLUX    FLUX  BURDEN     ORE
48392 MODYYR NO   NO  FLUXES                          A       B       C       D    LOAD    FLUX
4839  120558 11                                    2176    3808                     262   89216

49071   DATE CAMP PERTOP GAS                     TUYERE     TOP     PCT     PCT     PCT      NO
49072 MODYYR NO   NO TOP GAS                      PRESS   PRESS      CO     CO2      H2   CARDS
4907  120558 11                                     771     224      33    1550     146      12
```

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B. Characteristics of Fluid Flow and Flame Stability Criteria in a New Type of Burner.

A problem simpler by far than the foregoing was one concerned with relating the flow patterns in the channels of an experimental type of burner through the Reynolds number to a criterion of flame stability that incorporated the Reynolds number to a fractional power. Calculations of this type are always tedious, hence liable to error. In this instance an afternoon's work with the computer produced results that would have required several days of desk calculation.

RELIABILITY OF COMPUTERS

Reliability, as discussed here, has two aspects, namely: (1) The operability of the computer when it is needed and (2) its error-free performance when in operation.

At least a half-dozen types have been produced in quantities of a hundred or more. As a result, considerable experience has been accumulated in their use, and these mass-produced computers will have an availability ranging from 80 to more than 90 percent.

In the authors' experience, the computer described will operate error-free for days at a time. This computer when operating at its lowest speed (multiplication or division) need only operate error-free for 6 minutes to perform as many operations as a clerk performing three divisions per minute upon a desk calculator for an entire week. Repeated studies have shown that such clerical operations are 92 to 96 percent error-free if unchecked. Indeed, the greatest source of error in computing is in the preparation of the punched cards, a manual operation. However, the accuracy rises far above usual clerical operations when the cards are verified. In terms of probabilities, if the original punching and the verification are each only 92 percent correct, the proportion of errors in each stage will be 0.08, and the probability of an undetected error in both will be $(0.08)^2$ or a mere 0.64 percent. Further, errors in punching or computing usually can be detected by scanning the detailed tabulations of results. Because errors, when they occur, are usually evident, punched-card processing is sometimes criticized. What is lost sight of is the fact that the unrecorded error occurring in desk calculator operations (and slide rules, too) exerts its influence although often not detected. These thoughts are particularly pertinent to scientific calculations where the auditing and verification procedures so common in accounting work often are not applicable.

COSTS

The rental cost for a computer of the type described ranges from $4.16 to $5.42 per hour for one-shift operation, depending on the number of program steps, elements, selectors, and constants that are desired. The model at the Bureau of Mines is completely equipped. Rental of the necessary auxiliary card handling equipment averages $4.00 per hour. These costs include maintenance.

The personnel cost for computing will be highly variable. In general, the cost of card punching will be negligible for scientific problems, unless, as in the blast furnace case, the volume of cards is substantial. The major cost for one-time jobs will come from the programming, wiring, and checking work; the cost for the computer operator usually will be small.

DISCUSSION

The foregoing examples have been presented to indicate the scope of problems that have been solved successfully using a small electronic digital computer on a part-time basis during the past 3 years. A total of 32 programs were developed in this period to meet the demands of the experimental work of the Pyrometallurgy Laboratory.[8]

Close teamwork between the research technologist and the computer specialist has been mutually beneficial. A complete explanation of the problem by the technologist often results in a recommendation by the computer specialist that adds strength to the analysis and invariably conserves the time of both.

Participation in programming by research personnel has developed a seasoned approach to electronic computing with the result that the advantages of computing are foreseen before it is undertaken. As a corollary, several problems that might otherwise have been computed electronically have been calculated by hand because no advantage was foreseeable.

The examples cited represent only a small fraction of the types of problems that are amenable to solution on a small electronic digital computer. They do, however, exemplify the application of a number of techniques that make these machines so versatile and typify the several advantages that accrue from placing data in an accessible form, such as punched cards, followed by performing the calculations with an electronic computer.

The program for calculating the heat content of iron (I,A) illustrates the use of the branching function to choose the proper enthalpy-temperature equation from several alternatives by comparison with constant limit values. It also shows the use of internally produced constants. The generation of enough information for the next card followed by the computer's automatic operation upon it exemplifies in a simple form the program "loop", a distinctive and valuable property of these computers. The deck of cards that resulted has been used repeatedly to place values of the heat content of iron into cards that carried temperature readings from experimental runs, thus enabling summaries of heat input to be determined for hundreds of readings in a matter of minutes.

The blast furnace data processing program that was described in (I,B) is a good example of card-controlled programming. The distinctive 2-digit deck number would be an essential part of the card design in any event for it is needed in separating the 9 different card forms that are used for these data.

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[8] This represented approximately one-tenth of the experimental computer traffic at the center during this period.

The plug holes in the input-output panel that correspond to the deck numbers are connected to selector switches, and the machine automatically selects the proper program from what are essentially six different programs operating through one set of program steps. This is a rather highly developed program for this size of computer. By comparison, the previous example was worked out in a straightforward step-by-step application of a desk calculation pattern to the computer. These two examples illustrate how skill was developed in programming over the past 3 years on a variety of small jobs that aggregated perhaps 1 man-year.

The evaluation of the Fourier equation cited in (II,A) indicates how an approximate solution can be obtained for a mathematically complicated relationship with the aid of a computer specialist who is likely to have encountered a problem of the same pattern previously. This example also illustrates how scientists may readily undertake precise fitting of curves that either by the nature of the relationship or by inspection of the data could not be realistically construed as linear.

Finally, the calculation of relationships involving fractional powers and roots (II,B) becomes a simple exercise in programming and when thus carried out not only saves time, but results in virtually error-free results for a calculation that is highly liable to errors that can remain undetected when carried out with slide rules and log tables.

Contrasted to the popular view of electronic computers as gigantic complexes of expensive machinery, a moment's reflection upon the foregoing discussion will suggest that, in fact, small electronic computers not only are suitable for solving a broad range of scientific problems including many that arise frequently, but also hold out definite possibilities for marked reductions in cost compared to desk-calculated work. They also offer assurances of faster answers, improved accuracy, and continued accessibility of data. In a laboratory where the volume and the monetary value of computer traffic is far too low to consider the installation of a large computer, a small computer has been unquestionably beneficial and economical in solving a wide variety of the problems that arise in minerals research.

BIBLIOGRAPHY

BLANKENBAKER, JOHN. How Computers Do Arithmetic. Basic Digital Series No. 7. Control Eng., vol. 3, No. 4, April 1956, pp. 93-99.

BOLLES, E. E., AND ENGEL, H. L. Control Elements in the Computer. Basic Digital Series No. 9. Control Eng., vol. 3, No. 8, August 1956, pp. 93-98.

CARR, JOHN W., III. Solving Scientific Problems. Digital Application Series No. 2. Control Eng., vol. 3, No. 1, January 1956, pp. 63-70.

CARR, JOHN W., III, AND PERLIS, ALAN J. A Comparison of Large-scale Calculators. Digital Application Series No. 3. Control Eng., vol. 3, No. 2, February 1956, pp. 84-92.

______. Small-scale Computers as Scientific Calculators. Digital Application Series No. 4. Control Eng., vol. 3, No. 3, March 1956, pp. 99-104.

FOWLER, FRANKLIN, JR. The Computer's Memory. Basic Digital Series No. 8. Control Eng., vol. 3, No. 5, May 1956, pp. 93-101.

GRABBE, EUGENE M. Data Processing Systems: How They are Used. Digital Application Series No. 1. Control Eng., vol. 2, No. 12, December 1955, pp. 40-45.

HAMMING, R. W. Checking Techniques for Digital Computers. Basic Digital Series No. 13. Control Eng., vol. 4, No. 5, May 1957, pp. 111-114.

HOUSEHOLDER, ALSTON S. Solving Problems with a Digital Computer. Basic Digital Series No. 11. Control Eng., vol. 4, No. 1, January 1957, pp. 99-105.

KRUSE, BEN. Electronic Coal Analysis. Systems, vol. 22, No. 1, January-February 1958, pp. 22-23.

LEIFER, M., AND BLACKMAN, N. M. Communication Theory in Digital Systems. Basic Digital Series No. 4. Control Eng., vol. 3, No. 1, January 1956, pp. 72-77.

LERNER, IRWIN S. Digital Computers Need Orderly Number Systems. Basic Digital Series No. 2. Control Eng., vol. 2, No. 11, November 1955, pp. 82-89.

MAGINNIS, F. J. Electronic Computers - Engineering Timesavers. Gen. Elec. Rev., vol. 59, No. 3-4, May-July 1956, pp. 14-17.

NELSON, ELDRED. Digital Computers Need Logical Design. Basic Digital Series No. 3. Control Eng., vol. 2, No. 12, December 1955, pp. 60-66.

NOE, JERRE D. Data Processing Systems: How They Function. Basic Digital Series No. 1. Control Eng., vol. 2, No. 10, October 1955, pp. 70-77.

PERLIS, ALAN J. A Tool for the Mind. Carnegie Alumnus. vol. 44. No. 3, December 1958. pp. 4-7. 11.

REMINGTON RAND UNIVAC DIVISION OF SPERRY RAND CORPORATION. Programming Univac 60 and Univac 120 Punched-card Electronic Computers. 316 pp.

ROCK, SYBIL M., AND KLAMMER, WALLACE W. Programming the Computer. Basic Digital Series No. 12. Control Eng., vol. 4, No. 3, March 1957. pp. 119-123.

RUBINOFF, MORRIS, AND BETER, RALPH H. Input and Output Equipment. Basic Digital Series No. 10. Control Eng., vol. 3. No. 11, November 1956, pp. 115-123.

SCOTT, NORMAN R. Practical Circuits for Gating the Digital Computers. Basic Digital Series No. 5. Control Eng., vol. 3. No. 2, February 1956. pp. 93-98.

_____. Temporary Storage Elements and Special-purpose Tubes. Basic Digital Series No. 6. Control Eng., vol. 3, No. 3, March 1956. pp. 93-98.

WEGSTEIN, JOSEPH H., AND ALEXANDER, SAMUEL N. Programming Scientific Calculators. Digital Application Series No. 5. Control Eng., vol. 3, No. 5. May 1956. pp. 87-92.

WEIK, MARTIN H., JR. A Second Survey of Domestic Electronic Digital Computing Systems. Ballistics Research Laboratories Report No. 1010, Aberdeen Proving Ground. Md., June 1957. 439 pp. (Univac 60 is described on pp. 342-344. This report has been reprinted for public distribution by the U. S. Department of Commerce. Office of Technical Services. as Public Bull. 111996R.)

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